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The usage of lasers in military equipment.Part 1

Monograph

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THE USAGE OF LASERS IN MILITARY EQUIPMENT

Part 1

Monograph

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The monograph considers the possibility of using various types of lasers in optical systems for military applications: rangefinders, navigation systems, guidance and suppression systems, ABM defense and space-missile defense systems, as well as quantum data security systems.

For better perception, the monograph highlights the following physical principles of lasers: gas, solid-state, free electron, and fiber.

The monograph is intended for researchers, engineers and technicians engaged in research and development, manufacturing of laser devices for various purposes. It can also be useful for graduate students, students and cadets of the relevant specialties of higher educational institutions in the study of subjects related to laser and optoelectronic technology.

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CONTENT

ABBREVIATIONS USED

ARTSD — active radar target seeking device;
UAV — unmanned flying vehicle;
CEP — circular error probability;
GDL — gas dynamic laser;
GLONASS — Global navigation satellite system;
TSD — target seeking device;
DHJ — laser (double-heterojunction laser);
PFP — permanent fire position;
ADATS —surface-to-air and anti-tank missile system;
ER — efficiency rate;
ABM penetration aids — anti-ballistic missile penetration aids;
FEL — free electron laser;
LDR — laser designator rangefinder;
ICBM — intercontinental ballistic missile;
NMD — national missile defense;
CHL — continuous chemical laser;
MPL — maximum permissible level;
OES — optoelectronic system;
AD — air defense;
TTSD — television target seeking device;
MANPADS — man-portable air defense system;
ASM — anti-ship missile;
ABM defense — anti-ballistic missile defense;
RRI — retro reflection indicator;
ATGM — anti-tank guided missile;
SDI —Strategic Defense Initiative;
SSL — solid state laser;
TGM — tank guided missile;
GAM — guided artillery mine;

CLGP — cannon-launched guided projectile;

PRF — pulse repetition rate;

CDMA — Code Division Multiple Access;

GPS — Global Positioning System;

SBL — Space Based Laser;

SDI — Strategic Defense Initiative.

INTRODUCTION

The entire history of the creation of a laser is a little over 100 years old — only in 1916 the great Albert Einstein predicted the phenomenon of stimulated radiation as the physical basis of the operation of any laser. Since then, mankind has stubbornly sought and continues to seek ways to apply this invention, including in military weapons and technical equipment. Science fiction writers around the world have repeatedly described and still describe the use of "deadly rays" in military affairs. Any army provided with lasers gains an indisputable advantage over the enemy - a laser beam in the service of the military sinks the most powerful ships and shoots down the fastest aircraft with spectacular ease, ballistic and cruise missiles become an easy target for the laser.

Nevertheless, scientists and the military began to seriously develop laser weapons only after the end of World War II. To date, a large number of samples of various kinds of non-lethal laser weapons have been designed, and the day is not too far off when full-fledged laser guns will enter service with many of the world's largest armies, the prototypes of which have already been successfully tested. Indeed, the creation of lasers with promising military potential has been reported many times, but with the theoretical functionality of the laser itself, a number of related issues remain unresolved. Today, lasers as weapons still require heavy and bulky sources of energy of increased power, they cannot produce a pulse of sufficient duration, not to mention continuous operation, and the effectiveness of a laser beam on an enemy continues to depend on meteorological conditions. Nevertheless, there is no doubt that lasers will take an important place in the armament of aircraft combat ships and air defense systems. By now, the main directions for the introduction of laser technology into military affairs have been formed.

1. Laser detection and ranging (ground, airborne, underwater).
2. Laser communication.
3. Laser Navigation Systems.
4. Directed-energy weapon.

CHAPTER 1. THE USAGE OF LASERS IN MILITARY EQUIPMENT

1.1. The main types of lasers, their characteristics and laser radiation

The term "laser" originated as an acronym for "*light amplification by stimulated emission of radiation*". Laser is a device that converts pumping energy into electromagnetic energy of coherent, monofrequent and polarized radiation.

The physical principle of laser operation is *stimulated emission of radiation*. The essence of the phenomenon is that a quantum system in an excited state and under the influence of a photon can emit another photon. In this case, the absorption of the primary photon does not occur, and the emitted photon is completely identical to the first, i.e. has the same frequency, phase, polarization and propagation direction. In this way, light is amplified [1-5].

Three main parts of a laser can be identified: *a gain medium, a pump system and an optical cavity.*

Four aggregative states of the medium are used as the gain medium: solid, liquid, gaseous and plasma. The excited state of the medium is used. In the normal state, the number of particles N with energy E located at the energy levels of a gain medium follows the Boltzmann distribution [1, 10, 15]:

$$N = N_0 \exp\left(-\frac{E}{k_B T}\right), \tag{1.1}$$

where N_0 — the number of particles in the ground state (energy is assumed to be zero);

k_B — the Boltzmann constant;

T — the ambient temperature.

From this distribution it follows that the number of particles in an excited state decreases exponentially. Hence, it is unlikely that a photon passing through a and gas lasers. The active substance is exposed to powerful electromagnetic emission, which is selected so that it is absorbed, transferring the active centers from the ground to the excited state. Optical laser pumping is usually performed on the side of the laser substance.

Pumping is used in the form of:

— electric lamps, lamps with a high efficiency (a gas discharge lamp, an arc lamp, an excimer lamp, a flashlamp, etc.). An excimer lamp is a type of gas discharge lamps but with a narrow emission spectrum (up to 10 *nm)* and high specific output;

— semiconductor sources - LEDs or other lasers;

— focused solar radiation.

The lamp and the active medium are in a cavity with mirror surfaces that direct most of the lamp light to the medium for more efficient pumping. Liquid cooling is provided for high-power lasers.

Excitation by high energy particles. Electrons are typically used for this purpose. A beam of pre-accelerated electrons ($\beta-$particles) is directed to the target made of the active substance, causing excitation and ionization of active centers. This method is used in electron-pumped semiconductor lasers, but can also be used in other types of lasers. This method is used in electron-beam-pumped semiconductor lasers, but it can be applied to any other type of a laser.

Injection of minority carriers via the p-n junction. This method allows electrical energy to be transformed into coherent electromagnetic emission. The method is used in p-n junction lasers.

Gas discharge pumping. It is used in gas-discharge lasers, in which the excitation of active atoms and molecules is achieved by nonelastic collisions, which lead to the exchange of particle energy in a gas discharge cloud.

Chemical pumping. Chemical reactions are used to excite the end product of a reaction. In this case, the distribution of particles according to energy states must be inverse, and the transition of particles from the upper energy level to the lower one is accompanied by electromagnetic emission. The speed of the chemical reaction should be higher than the speed necessary for reaching the equilibrium distribution over the energy levels, otherwise the energy of the chemical reaction will be used for heating the gas mixture.

Gas-dynamic pumping. The method is used in gas lasers where working gas which is heated to a high temperature can be cooled quickly. Gas molecules are retained in long-lived (metastable) states when they make transition in an equilibrium state, as a result of which population inversion can be achieved.

Nuclear pumping. Excitation of the active medium is carried out by ionizing radiation from a nuclear explosion (gamma-ray photon, elementary particles and fission fragments of high-energy atoms). Direct conversion of the released nuclear energy into laser emission occurs in the active zone, consisting of fissile material and a laser medium. It bypasses the mid-stage of thermal energy.

Nuclear pumping is used in gas lasers. Although studies are being conducted on the possibility of creating lasers with such pumping in condensed matters. However, the most important obstacle is radiation damage, namely the formation of displaced atoms and color centers in solid-state lasers, radiolysis, and the formation of gas-vapor bubbles on nuclear tracks in liquid lasers.

Experimental studies of nuclear pumped gas lasers were carried out by using nuclear reactors and nuclear explosive devices. In the former case, lasers operate in quasi-continuous or continuous modes (pulse width is $\geq 0{,}1$ *ms*). In the latter case, lasers operate in pulsed mode having pulse width of ≤ 10 *ns.*

High energy predetermines the X-ray wavelength range, although the emission wavelength can cover the visible, including the far infrared range.

Consider the main types of lasers according to the used active medium, the operation range, and, if possible, the application in a particular area of military affairs.

1.2. Gas lasers

Gas discharge lasers with pressure from 1 *mm* to 10 *mm* Hg can be excited by a self-maintained discharge. Three groups of gas discharge lasers can be identified:

molecules *AB* is created, the value of the vibrational energy exceeds the amount of energy which is attributed to the rotational and translational degrees of freedom of molecules. That nonequilibrium gas is an active medium with a population inversion for vibrational transitions.

The key parameters of a chemical laser are chemical efficiency of η_x and electrical efficiency of $\eta_{э}$. Chemical efficiency is the ratio of the laser emission energy to the amount of energy released during chemical reactions. Electrical efficiency is the ratio of the laser emission energy to the amount of energy used for triggering a chemical reaction.

The usage of chemical lasers is based on the possibility of obtaining lasing in a wide range of the IR-spectrum and achieving high efficiency and lasing power. Along with other types of high-power lasers, chemical lasers are used for studying laser controlled thermonuclear fusion, laser probing of the atmosphere, laser spectroscopy, laser chemistry and other fields.

The active medium *of hydrogen-fluoride lasers* (*HF (DF*)) is hydrogen fluoride or deuterium fluoride. Lasing occurs within the range from 2,7 μm to 2,9 μm and from 3,6 μm to 4,2 μm with a high value of η_x (~10 %).

They work on the basis of substitution reactions. The pumping source is the combustion reaction of ethylene and nitrogen trifluoride (NaF_3) which is triggered by electric discharge in pulsed mode with the formation of atomic fluorine. The temperature of the combustion chamber is 1500—2000 *K* and the pressure of the laser zone is $(6—27)\cdot 10^{2}$ *Pa*. The generated mixture of gases is passed through a special nozzle which splits the stream into many filaments with a diameter of up to 2 *mm*, which are accelerated to supersonic velocity and are partially cooled during expansion. The stream is mixed with the deuterium stream of D_2 at the nozzle outlet and the generated particles are created by means of a chemical reaction of $(D_2 + F = DF^* + H)$.

The usage of deuterium fluoride instead of hydrogen fluoride has been motivated by the fact that the stream of HF which is generated in the combustion chamber deexcites the excited molecules of HF^* in the laser area. Since a large amount of heat is released during combustion, and only part of the energy (up to 15 %) is emitted with emission, the gas mixture is diluted with a helium stream to reduce thermal effects.

The electrical efficiency of lasers is η_e~ 3 %. Megawatt power is achieved in constant mode and terawatt power is achieved in pulsed mode.

A *chemical oxygen iodine laser* uses a reaction of combustion in a flame of singlet oxygen[1] and iodine. Each molecule of singlet oxygen has energy of ~ 1 *eV*. Since singlet oxygen emits energy poorly (half-life period is ~ $4{,}3\cdot10^3 s$), it is impossible to use this energy directly.

Therefore, the work should proceed as follows: the stream of iodine molecules of I_2 is mixed into the stream of singlet oxygen. The iodine molecule breaks up into atoms quickly enough by means of singlet oxygen energy:

$$2O_2(^1\Delta) + I_2 \rightarrow 2O_2(^3\Sigma) + 2I.$$

If all goes well, there occurs the transition of iodine atoms to the excited state upon collision with singlet oxygen

$$O_2(^1\Delta) + I \rightarrow O_2(^3\Sigma) + I^*.$$

The excited atomic iodine forms the active medium of the laser. Singlet oxygen is obtained by passing molecular chlorine through a mixture of hydrogen peroxide with alkali.

Fig. 1.8 shows the structural scheme of a laser with gas discharge production of singlet oxygen. The laser consists: 1 — high-pressure chamber that contains an oxygen mixture, for example,(O_2, D_2, Ar); 2 — device of supersonic gas outflow;

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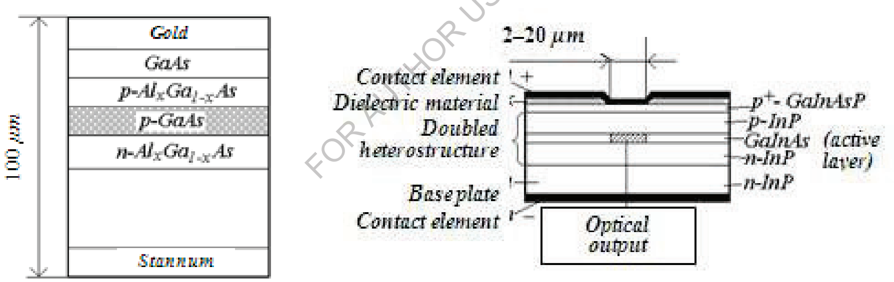
[1] Singlet oxygen is an oxygen molecule in the first electronic excited state. It is denoted by a symbol of $O_2(^1\Delta)$. Unexcited oxygen molecule is denoted by a symbol of $O_2(^3\Sigma)$

The gain in semiconductor lasers can reach 10^3 cm^{-1}, and in quantum-dimensional structures can reach 10^4 cm^{-1}. As a consequence, there is a possibility to use active elements of small sizes. The length of the active region can range from several tens to several hundred microns.

Fig. 1.13, a shows a scheme of a double heterojunction semiconductor laser (DHSL). With a significant thickness of the active layer, in addition to the main mode, higher order modes can be excited. Such undesirable modes are eliminated by reduction of d.

The appearance of waveguide modes can be possible with a large width of the active region. The interaction between them can lead to beats, current instabilities and increase of noise. These phenomena can be avoided in strip DHSLs (fig. 1.13, b). The completion of the active region of the injection heterolaser in the form of a narrow strip provides effective selection of transverse modes and a stable laser operation.



a) b)

Fig. 1.13. Shows a scheme of a double heterojunction semiconductor laser (a) and the structure of a strip DHSL (b) [1-5, 20-25]

The wavelength can range from near-UV region to far-IR region for semiconductor lasers. It depends on the material and structure of the active region.

Semiconductor nitrides such as *Ga* and *Al* provide operation in the near-UV, violet and blue regions; the operation is provided in the red and near-IR region by compounds based on *Ga, Al* and *As;* the operation is provided in the near and mid-IR region by compounds based on *In, P* and *Sb;* the operation is provided in the middle and IR regions by lead salts; the operation is provided in the mid-IR and terahertz regions by quantum-cascade lasers; semiconductor lasers are used in the production of target indicators.

1.5. Fiber Lasers

Rare earth-doped fiber can operate as a high-performance laser in the visible and near-infrared ranges. The feedback communication in such a laser is carried out using a bragg grating built into the fiber, and pumping is done by laser diodes through multimode fibers, which are connected to a core with a multilayer coating. Double-coated optical fibers are used in order to prevent nonlinear effects due to high power density (fig. 1.14).

Multi-layered silica glasses doped with ytterbium have high capacity level. In continuous mode, the output power can be a few kilowatts with an efficiency greater than 25 %. [48-70].

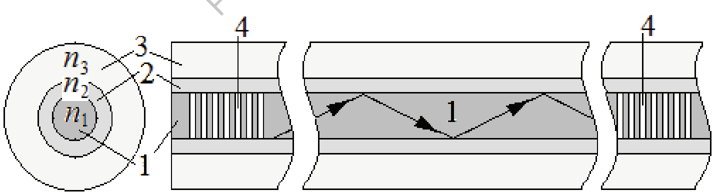


Fig. 1.14. Diagram of a fiber laser construction: 1 — core (active fiber) with a high refractive index; 2 — inner shell (pump shell); 3 — outer (protective) shell with the lowest refractive index; 4 — fiber bragg gratings

The power of an erbium fiber laser can reach hundreds of watts in continuous mode with an efficiency of more than 10 %; the line width does not exceed 400 *GHz,* in the range from 1530 *nm* to 1570 *nm.*

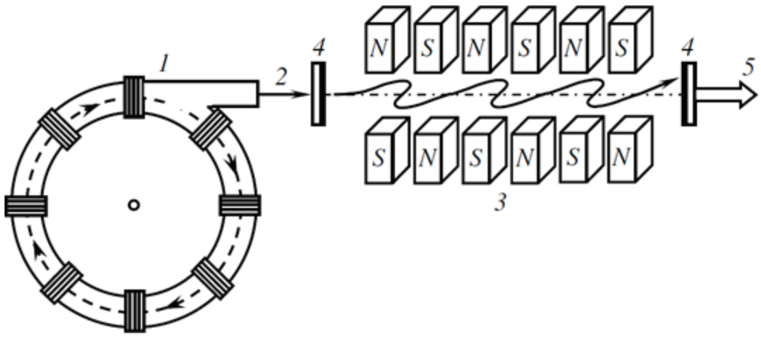


Fig. 1.15. Shows the scheme of a free-electron laser:
1 — an electron accelerator; 2 — an electron beam; 3 — a shaping amplifier of wiggler field; 4 — a cavity mirror; 5 — a laser beam [1, 8, 10]

The maximum efficiency factor of FEL, defined as the ratio of the maximum energy given to laser emission to the initial electron energy, is relatively small and amounts from 10^{-3} to 10^{-2}. The work is currently performed to increase efficiency factor.

FELs have a number of distinctive features.

Firstly, the emission wavelength is determined by the undulator parameters and the electron energy, and, therefore, can vary from hundredths of a nanometer to millimeters and can be tuned in a smooth manner.

Secondly, electron beams with an average power of the order of tens of megawatts and an average power density of up to hundreds of megawatts per square millimeter makes it possible to create FELs with an average power of up to several megawatts.

Thirdly, the relatively low optical density of the medium makes it possible to obtain emission with extremely small (diffraction) angular divergence. These features determine the possibility of using FEL in various fields, in particular, for energy transfer in space and in the ballistic missile defense.

1.7. Nuclear-pumped X-ray laser

Energy is generated in the X-ray range of electromagnetic emission. Existing X-ray lasers are actuated in a variety of methods. The main of them are nuclear or thermonuclear explosion, inverse emission of excited plasma media, emission of excited solid-state media or synchrotron emission of an electron beam when flowing through a region of an oscillating magnetic field.

It is necessary to overcome fundamental difficulties while creating short-wave lasers. In order to maintain the inverse population of the upper levels, the excitation power should be much greater than that which is scattered in the form of spontaneous emission in a medium whose magnitude is proportional to the third power of the emission frequency. The power which is necessary to maintain the inverse population for an X-ray laser with a wavelength of about 0,5 *nm*, the density of pumping energy should be 10^{10} —10^{15} W/cm^2. A high energy level can be achieved only by means of a nuclear explosion or in the focal spot of a high-power pulsed laser.

Any substance at the center of the explosion turns into plasma which in cold condition forms atoms which are already excited. If a long rod is made of the raw material, conditions for the occurrence of the stimulated emission generated as a result of the transition of atoms to the ground state can be created in it along the axis. It is obvious that a laser is pulsed and consumable.

Since the creation of mirrors for working with X-rays is a challenging task, it is preferable that the X-ray laser operates without a resonator. In this case, the beam divergence will be determined by two factors: diffraction and rod geometry. To be more precise, the largest value of them. If at the moment of recombination the plasma bunch expands to 1 mm (which is real), then the beam divergence will be of the order from 10^{-4} to 10^{-5}.

1.8. The impact of laser emission on the elements of rocket-and-space systems

The impact of laser emission on the material of the irradiated object depends on the laser pulse duration $\tau_{imp}(s)$ and the thermal diffusivity of the material $\chi(m^2/s)$. The latter is a physical value that characterizes the change rate (equalization) of a substance temperature in nonequilibrium thermal processes. The depth of heat penetration of δ (m) is determined by the following equation:

$$\delta = \sqrt{\chi \tau_{imp}}. \tag{1.21}$$

The value of χ depends on the material density of ρ (*kg/m³*), the isobaric specific heat of c_p (*J/(kg·K*) and thermal conductivity of the material κ*(W/(m·K)*:

$$\chi = \kappa / (c_p \cdot \rho). \tag{1.22}$$

The values of the thermophysical properties of some materials used in rocketry are shown in the table 1.1.

To estimate the specific energy of laser emission which is necessary for heating a plate with a thickness of δ during exposure to its destruction, you can use the approximate equation for thin plates:

$$E = \left[c_p \cdot \left(T_{melt} - T_0\right) + L_{melt}\right] \cdot \rho \cdot \delta, \tag{1.23}$$

where T_0, K— initial temperature;

T_{melt}, K — melting temperature;

L_{melt}, *J/kg* — specific heat of fusion.

Table 1.1

Thermophysical properties of materials

Material	Density $\rho\cdot10^3$, kg/m^3	Specific-heat c_p, $(J/(kg\cdot K)$	Thermal-conductivity κ, $W/(m\cdot K)$	Temperature-conductivity χ, m^2/s
Aluminium	2,7	920	202—236	$8{,}4\cdot10^{-5}$
Titanium	4,5	530	20	$9{,}3\cdot10^{-6}$
Steel	7,8	500	15	$1{,}172\cdot10^{-5}$
Copper	8,9	380	401	$1{,}11\cdot10^{-4}$
Magnesium	1,74	1000	100	—
Carbon	2,5	750	340	$2{,}165\cdot10^{-4}$
Carbon fiber-reinforced plastics	1,3—1,9	600—1500	0,75—0,90	$(5{,}0—8{,}0)\cdot10^{-7}$
Glass fiber-reinforced plastics	1,6—2,2	700—4200	0,21—0,33	$(0{,}3—1{,}0)\cdot10^{-7}$

Taking into account the exposure duration required for the destruction of the laser power density:

$$I = E / \tau, \tag{1.24}$$

where I, τ — exposure time of laser emission (pulse duration in seconds).

The thermodynamic properties of some structural materials are shown in the table 1.2.

It is possible to estimate the laser energy requirements for each scenario by using the data of this table.

The solution to a problem of countering weapons of mass destruction was initially examined. That is the destruction of warheads of intercontinental ballistic missiles (ICBMs) at high altitudes. It must be noted that the main part of the trajectory of missiles passes at altitude of thousands of kilometers above the Earth's surface, i.e. in space, from where a warhead heads toward the Earth at a speed of several kilometers per second, while heating up to very high temperatures. To protect a warhead and a control system from overheating, a special high-temperature thermal insulation with thickness of several centimeters must be used.

Table 1.2

Thermodynamic characteristics of some materials

Material	Melting temperature T_{melt}, K	Heat of fusion L_{melt}, J/kg	Boiling temperature T_{boil}, K	Boiling heat L_{evap}, J/kg
Aluminium	933	$3{,}93 \cdot 10^5$	2772	$1{,}09 \cdot 10^7$
Titanium	1941	$3{,}15 \cdot 10^5$	3560	$1{,}0 \cdot 10^7$
Copper	1356	$2{,}13 \cdot 10^5$	2863	$0{,}48 \cdot 10^7$
Magnesium	924	$3{,}7 \cdot 10^5$	1380	$0{,}54 \cdot 10^7$
Tungsten	3683	$1{,}84 \cdot 10^5$	6173	—
Steel	1770	$2{,}05 \cdot 10^5$	3135	$0{,}64 \cdot 10^7$
Carbon	3970	–	4300	$5{,}92 \cdot 10^7$

Preliminary estimates show that the diameter of the laser spot on the surface, sufficient to cause irreparable damage, should be 0,1—0,2 *m*. We will determine what laser emission energy of E is needed to destroy (evaporate) a carbon thermal insulation layer with thickness of 1 cm which is heated to the decomposition temperature:

$$E \approx \rho \frac{\pi d^2 \delta}{4} L_{evap}, \qquad (1.25)$$

where d — diameter of the laser spot.

We will obtain the destruction energy of the protective layer $E \approx 27$ *M/J* by substituting the numerical values of $\rho = 2{,}25$ kg/m^3 (density of graphite), $L_{evap} = 5{,}92 \cdot 10^7$ J/kg (boiling heat), $\delta = 0{,}01$ m (thickness of the protective layer), $d = 0{,}16$ m (the diameter of the laser spot).

While the obtained value is an estimate of the energy absorbed by the material, the energy emitted by the laser, taking into account path losses, should be much higher.

The value of the specific output of laser emission at which optical-induced breakdown in the atmosphere occurs is I_{br} = 10^{15} W/m^2. Consequently, the minimum pulse duration for the energy value obtained above, at which the emission propagates in the atmosphere without significant distortions, must exceed [1-10]:

$$\tau_{pulse} > \left(E / \frac{\pi d^2}{4} \right) / I_{br} \approx 10^{-6} s. \qquad (1.26)$$

Less strict requirements to laser energy can be for destruction missions of ICBM in active sections of the trajectory. In such a case, the laser must be placed in space under direct visibility of a rocket taking off.

The energy threshold of damage can be estimated by the following equation:

$$E \approx \left[c_p \cdot \left(T_{melt} - T_0 \right) + L_{melt} \right] \cdot \rho \cdot \frac{\pi d^2}{4} \cdot \delta. \qquad (1.27)$$

The thickness of an aluminum housing of the tanks or a propulsion system of ICBM does not exceed 0,5 *cm*. In this case, the damage threshold is significantly reduced. We will obtain E = 0,3 *MJ* by substituting in the values of the physical parameters for aluminum ($c_p \approx 1050$ $J/(kg \cdot K)$, T_{melt} = 933 K, T_0 = 273 K, L_{melt} = $3{,}93 \cdot 10^5$ J/kg, $\rho \approx 2{,}7 \cdot 10^3$ kg/m^3, d = 0,16 m, $\delta = 0{,}005$ m).

The energy threshold for the elements of the missile carrier turned out to be two orders of magnitude lower than for the warhead. It should be considered that the effect involves the large distances from a laser to a target (hundreds and thousands of kilometers) at a relatively high velocity of travel.

Despite the obvious technical difficulties of implementing missile defense missions by means of lasers, it did not stop the development of “strategic” laser systems for missile defense.

It is expected that systems will be able to detect and destroy many different objects, such as cruise missiles, unguided missiles, unmanned aerial vehicles, as well as ground objects, cars and missile launchers.

1.9. The impact on hardware of unmanned aerial vehicles (UAVs)

UAVs are used to destroy ground objects. Their performance characteristics vary depending on the type of a target.

UAVs are divided according to interrelating parameters such as mass, time, range and flight altitude. You can divide them into the following categories:

— micro- weight up to 10 *kg*, a flight time of about 1 hour and a flight altitude up to 1 *km*;

— mini- weight up to 50 *kg*, a flight time of several hours and an altitude from 3 *km* to 5 *km*;

— medium (midi) weight up to 1000 *kg*, a flight time from 10 *km* to 12 *km* hours and an altitude of 9 — 10 *km*;

— heavy weight at flight altitude up to 20 *km* and a flight time of 24 *h* or more.

This choice of target seems to be the most appropriate from an economic point of view. Unmanned aerial vehicle of heavy and medium weights can be destroyed by modern anti-aircraft weapons, such as guided missiles. At the same time, the usage of such expensive means against unmanned aerial vehicle of mini and micro weights is useless from a technical and economic point of view.

The data given in table 1.1 and 1.2 are sufficient for a rough estimate of the energy characteristics of a tactical laser which is capable of causing sufficient damage to UAVs of micro weights. The surface area of the wings is at least 0,5 m^2 when the weight of micro UAV is 2 *kg* and the wing load is 4 kg/m^2. If the weight of

Resolution ratio is characterized by the ability to separately determine the coordinates of closely spaced targets, and each coordinate has its own resolution ratio.

Last but not least, there are characteristics such as *effectiveness against jamming* and *reliability*. This is the ability of optical laser radar to operate in conditions of natural and artificial interference and maintain its characteristics within specified limits under specified operating conditions.

Fig. 2.1 shows a diagram of optical laser radar for measuring the four main parameters of an object: range, azimuth, angle of sight and speed. Depending on the purpose for which the radar is intended, a distinction is made between range finders, speed meters and radars (localizers) themselves.

The constant speed of the laser beam propagation makes it possible to create a *laser rangefinder* — a device for range measurement. Rangefinders are divided into pulse and phase devices according to the principle of operation.

Pulse laser rangefinder consists of a pulse laser and a radiation detector. It is possible to calculate the distance between the laser and the reflecting object by measuring the time it takes for the beam to travel to the reflector and back, and using the light velocity value:

$$L = \frac{ct}{2n}, \tag{2.1}$$

where c — is the light velocity in vacuum;

t — is the transit time of the pulse in the forward and reverse directions;

n — is the refractive index of the medium in which the radiation propagates.

The sounding pulse sent to the object also starts the time counter in the rangefinder. When the pulse reflected by the object comes to the rangefinder, it stops the counter. The object distance is determined by the time interval (delay of the reflected pulse).

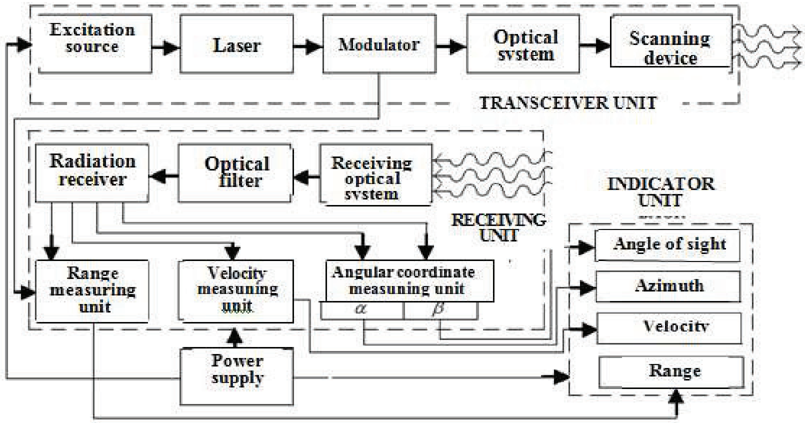


Fig. 2.1 Diagram of an optical laser radar

The measurement accuracy depends on the measurement accuracy of the pulse transit time, and it is affected by a number of factors: the state of the atmosphere, the presence of scattering media, the nature of the reflecting surface, etc. Pulsed laser rangefinders have a long operating range, because the pulse can be generated with high power and increased stealth operating only for the duration of the pulse. Therefore, pulsed laser rangefinders are usually used in military sighting units.

In the phase ranging method, laser radiation is modulated in a sinusoidal manner using a modulator (usually an electro-optical crystal that changes its parameters under the influence of an electric signal). A sinusoidal signal with 10—150 *MHz* frequency (measurement frequency) is most often used. The reflected radiation enters the receiving optics and photo detector, where the modulating signal is generated. Depending on the object distance, the phase of the reflected signal is changed relative to the signal phase in the modulator. The object distance is determined by measuring the phase difference.

The choice of the laser radiation wavelength is determined first of all by the requirements for the safety and stealth of the device.

The first experiments date back to the 1960s, and now laser rangefinders are used in ground-based military equipment (tank rangefinders, artillery rangefinders), in aircraft fleet (rangefinders, altimeters, target designators) and in the navy. This equipment has passed combat tests in Vietnam and the Middle East. The rangefinders are now in service in many armies around the world [30-40].

One of the first laser rangefinders was commissioned by the U.S. Army in 1963. It was used at the front observation posts of the ground forces. Its source of radiation was a ruby laser with 2,5 *W* output capacity, 30 *ns* duration of the pulse and the range of measured distances from 200 *m* to 10000 *m*. Integrated circuits were widely used in the rangefinder design. Emitter, receiver and optical elements are installed in the monoblock, which has scales of the fine reading of azimuth and angle of sighting. The rangefinder was powered by 24 *V* nickel-cadmium battery with providing 100 range measurements without recharging.

In another artillery rangefinder, also commissioned for service, there is a device for the simultaneous determination of the range of up to four targets lying on one straight line by sequential strobing 200—300 *m* distances.

Laser rangefinders installed on modern tanks allow you to measure the range to a target within 200—8000 *m* (on American and French tanks) and 200—10000 *m* (on British and West German tanks) with up to 10 *m* accuracy.

Most of the active elements of laser rangefinders currently installed on western-made tanks and infantry fighting vehicles are based on yttrium-aluminum garnet crystal with an admixture of neodymium. These lasers generate radiation at 1,064 μm wavelength.

There are also laser rangefinders based on a ruby laser λ = 0,6943 μm). One of the rangefinder types is laser altimeter for aircraft height finding. Let us give as an example the parameters of altimeters of the LD 90-3 series: the interval of height measurements is, 1—1900 *m* at h < 100 *m* accuracy is ± 25 *mm,* at h > 500 *m* accuracy is $\pm 0{,}9\,m$; the data output speed changes depending on the flight altitude: at > 1350 *m* the altitude data is output after 1—3*s*, at low altitudes — after 0,1*s*.

Currently, rangefinders use semiconductor lasers with short picosecond pulses, which make it possible to bring the range finding accuracy to millimeters.

The next stage of the military use of laser rangefinders is their integration with the infantryman's individual small arms. An example is the Belgian machine gun FN F2000. A special computerized fire control module, which includes a laser rangefinder and a ballistic computer, can be installed on the F2000 instead of a sighting unit. Based on the data on the range to the target, the computer sets the aiming mark of the sighting unit both for firing from the machine itself and from the under-barrel grenade launcher (if installed).

Laser rangefinders hit the free market in the Western world for the first time in 1992. At that time Leica and then Swarovski produced the first rangefinders with a safe laser. A little later, Swarovski offered a rangefinder model integrated into the telescopic sight. However, the cost of these devices (several thousand dollars) was very high, and laser rangefinders have actually become available to the general consumer since 1996, after Bushnell offered relatively inexpensive devices. Since then, some other companies have also begun to actively work in the same direction, Nikon (Japan) and Newcon (Canada) can be noted among them. But still, at the moment, only Bushnell has managed to seize the leading position.

In the USSR (and then in Russia), such equipment was only available to the army men, and military models use powerful lasers, the radiation of which, when in contact with the eyes, often leads to loss of vision, so they are not allowed to get to the consumer market.

The laser rangefinder system allows you to determine not only the distance to the target, but also the target speed. An important feature of such devices is the accumulation mode characterized by multiple sensing of the target by laser pulses.

Target speed V can be determined from two range measurements, R_1 and R_2, taken with a time interval (base) T_1:

$$V = (R_2 - R_1) / T_1. \qquad (2.2)$$

Each range measurement is made by determining the time between the moments of the sensing pulse emission and the return of the reflected signal

$$R = c \cdot t / 2, \tag{2.3}$$

where c — is the light velocity.

The maximum speed measurement error ΔV is determined by the range measurement error ΔR and the base T_1:

$$\Delta V = 2\Delta R / T_1. \tag{2.4}$$

The error ΔR does not contain a systematic component, which is compensated for by subtracting two range measurements. The random component of the error can be reduced by averaging the results of multiple measurements in the accumulation mode. With n — multiple repetitions of the procedure, the root mean square error of the series will be:

$$\sigma_n = \sigma_1 \sqrt{n}, \tag{2.4}$$

where σ_1 — is the root mean square error of one measurement.

As a rule, most methods assume uniform filling of the measurement interval with range measurements with ΔT period. It can be shown that such a mode is not optimal: measurements close to the boundaries of the measuring interval have the greatest informational content, and the results obtained in the middle of the interval have little effect on the measurement accuracy. Therefore, to determine the speed, the entire interval is divided into two groups, which are spaced to the edges of the measurement interval. In this case, with the same number of measurements, the measurement accuracy increases several times (it depends on the total number of measurements).

Currently, it has become possible to determine the distance to artificial earth satellites (AES) with millimeter accuracy using laser ranging. Measuring the distance to spacecraft makes it possible to refine the orbits, and the observation of specialized satellites equipped with retroreflectors makes it possible to determine the parameters of the Earth's rotation.

2.2. Laser Navigation Systems

Before considering the use of lasers in navigation, let us briefly dwell on modern navigation systems. Currently, there are three global navigation systems in the world that provide full and uninterrupted coverage of the globe - the American GPS (Global Positioning System), the Russian GLONASS (Global Navigation Satellite System) and the French DORIS (Détermination d'Orbite et Radiopositionnement Intégré par Satellite). There are also two regional ones - Indian IRNSS and Japanese QZSS (Quasi-Zenith Satellite System). The radio carrier frequencies are in the 1176—1615 *MHz* range. The measurement accuracy has an error equal to 10—15 *m* without a ground correction system and 10—15 *cm* with such a system [50-60].

Let's briefly consider the GPS system, which consists of three main segments: space, control and user segment.

The space segment consists of 32 satellites orbiting the Earth's average orbit.

The control segment is the main control station and several additional stations, as well as terrestrial antennas and monitoring stations.

The user segment is represented by government-run GPS receivers and hundreds of millions of ordinary user-owned receivers.

GPS satellites broadcast a signal from space, and all GPS receivers use this signal to calculate their position in space in three coordinates in real time.

In order to determine three-dimensional coordinates, a GPS receiver needs equations: $|\bar{r} - \bar{a}_i| = c(t - \tau)$, where $\bar{r}$ — is unknown consumer radius vector; $\bar{a}_i$ — is the radius vector of the i-satellite, c — is the light velocity; t — is the time when the signal is received from the i -satellite according to the user's time; τ — is the unknown moment of time of the synchronous signal emission by all satellites according to the user's time,

Positioning in the GPS network is carried out by measuring the distance from the receiver to several satellites, the location of which is precisely known at the current time.

Contacting the first satellite provides information only about the range of possible receiver locations. The intersection of two spheres will give a circle, three - two points, and four - the only true point on the map. Our planet is most often used as one of the spheres, which makes it possible to position only three satellites instead of four. The theoretical GPS positioning accuracy is 2 *m* (in practice, the error is much larger).

Each satellite sends a large set of information to the receiver: exact time and its allowance, almanac, ephemeris data and ionospheric parameters. Navigation satellites are equipped with highly accurate cesium clocks, while receivers are equipped with much less accurate quartz clocks. Therefore, to check the time, contact is made with an additional (fourth) satellite.

Satellites and individual ephemeris data are transmitted, on the basis of which the orbital deviations are calculated. And given that the speed of light is not constant anywhere except vacuum, the signal delay in the ionosphere is taken into account.

Data transmission in the GPS network is carried out strictly at two frequencies: 1575,42 *MHz* and 1224,60 *MHz*. Different satellites broadcast the signal on the same frequency, but use CDMA (Code Division Multiple Access). That is, the satellite signal is just noise, which can only be decoded if the corresponding PRN-code (pseudo-random code) is available. The data transfer rate in the GPS network is about 50 *bit/sec*.

The GLONASS system was fully deployed in 1995 and included 24 satellites, although the first tests were started back in 1982 with the launch of the Cosmos-1413 satellite.

The GLONASS system includes the following components:

— space complex consisting of an orbital group, launch vehicles and ground control complex;

— differential correction and monitoring system, as well as regional and local monitoring and differential navigation systems;

— high-precision a posteriori ephemeris-time information system;

— systems for the operational determination of the parameters of rotation and orientation of the Earth and the system for the formation of the state scale of universal time;

— navigation user equipment.

Unlike other satellite navigation systems, the French DORIS is based on a system of stationary ground transmitters, the receivers are located on satellites. The operation principle of the system is associated with the use of the Doppler effect.

The measurements are performed at two frequencies: 2,03625 *GHz* — for measuring the Doppler shift and 401,25 *MHz* — for correcting the propagation delay of the signal in the ionosphere. The 401,25 *MHz* frequency is also used for measurement time stamping and transmitting auxiliary data. The choice of a system transmitting only to the satellite makes it possible to fully automate the operations of beacons and communication lines for centralized data delivery to the processing center.

In conclusion of this section, we will focus on some of the problems of laser ranging. In the past few years, in order to reduce the likelihood of detecting an object in aircraft and ships, so-called stealth technologies have been used in the materials of the external layout — the shape of the object and absorbing coatings that reduce the ability to register the reflected signal. Structures with non-uniform surfaces, including multicomponent coatings and composite materials, are used. In this case, part of the signal is absorbed by the coating, and the rest is scattered so that it does not return back to the observing laser system. Developments in the field of optical invisibility have been going on for a long time, but so far progress has been modest. American scientists have suggested using fiberglass light guides, the surface of which was cut

— identification of the background and the possibility of highlighting an object relative to this background requires probing at different angles of incidence. Background surfaces are most often gray bodies, i.e. their reflectivity depends on the angle of incidence of radiation;

— measurement of the polarization characteristics of radiation makes it possible to study the dependence of the reflectivity on various parameters of the surface structure: the composition and size of particles of composite materials, the shape and size of surface irregularities associated with the methods of processing the irradiated surface;

— to improve the metrological characteristics of systems and the probability of detecting and recognizing objects, it is necessary, first of all, to increase the signal-to-noise ratio by choosing radiation sources and controlling the parameters of laser radiation.

distance of about 2,5 *km* from the target, CLGP goes into homing mode. The Centimeter complex operates differently. Its correction, set by a reflected laser beam, occurs on the final section 20—600 *m* of the ballistic trajectory. The projectile is equipped with four pulsed gunpowder engines located perpendicular to its axis, in order to perform the correction. At the right moment, the engines are triggered, and several pulses achieve a trajectory correction. Each technology has its pros and cons.

The accelerating jet engine of the Krasnopol allows to shoot for longer distances (20 *km* vs 15 *km* of the Centimeter), but in case of irregular operation of the correction system (technical failure, sudden interruption of the LDR - target optical communication due to smoke, snow discharge, etc.), the Krasnopol flying in planning mode deviates significantly from the target. The Centimeter behaves like a standard unguided projectile under the same circumstances.

Krasnopol begins a smooth trajectory correction 2,5 *km* before and has a larger maneuver than Centimeter to select deviation from the target. The latter starts the correction from 600 *m*. Therefore, Krasnopol firing is conducted without zeroing, and when using Centimeter, it is recommended to fire 1—2 projectiles with spotting charge.

Smooth and continuous steering of the Krasnopol provides it with greater hitting accuracy than the pulse Centimeter. However, while steering, Krasnopol's spotter has to highlight the target for 5—12*s*. The Centimeter has enough illumination for 1—3*s*. This significantly increases the security level of the spotter. It is dangerous to do the highlighting for a long time: the infrared laser is invisible only to the naked eye, and the troops today are saturated with infrared technology, and the illumination is quite easily detected; then the enemy takes all measures to destroy or capture the spotter [50-60].

The Krasnopol system is a complex device with precision mechanics. The Centimeter has almost no mechanics, the technology is designed for robotic production. This makes it 2—3 times cheaper.

Another advantage of the Centimeter is salvo fire. Due to planning, the Krasnopol projectiles fly up to the target unevenly, and the smoke from the explosions of the first projectile, as a rule, interferes with laser target designation for subsequent projectiles. A volley of three to six guns with Centimeters will reach the target almost simultaneously.

In Russia, cannon-launched guided projectiles were created for battalion artillery. These are: the 120-*mm* Kitolov-2 CLGP for the Nona-type guns, the 122-*mm* Kitolov-2M CLGP for the D-30 and 2S1 Gvozdika howitzers, and the Gran guided mine for 120-*mm* mortars. The principle of operation of these projectiles is the same as for the Krasnopol CLGP.

In the early 70s, the Americans developed the Shilleila TGM. The rocket was guided semi-automatically by infrared beam. Both M60A2 and M551 tanks appeared with 152 *mm* cannon launchers. The launch was carried out through the barrel of the cannon, which also fired conventional high-explosive fragmentation and cumulative projectiles. However, after about five years, the production of these machines was discontinued due to the high cost and unsatisfactory performance of the Shilleila and standard projectiles. Attempts by Western designers to create a TGM for 105 *mm* and 120 *mm* tank calibers were unsuccessful. Work on the rocket tank was stopped, considering the case to be hopeless.

In the context of aggravated military conflicts and terrorist activity, security issues are becoming one of the most urgent tasks of law enforcement agencies.

One of the few unmasking signs of the enemy's use of optical observation and aiming devices is their optical contrast. The flashes and pops of a sniper rifle, shockwaves, swirls and heat generated by a bullet in flight, as well as light reflection from a telescopic sight or other optical device are such signs that allow detecting the actions of a sniper associated with a shot.

The vortices change the density of the air mass, which can be detected by laser systems. In addition, infrared sensors can detect heat and shape the heat path of the projectile.

Thus, the main unmasking signs of a shot are sound, flash, smoke and dust, which rise with powder gases. In accordance with this, three main methods of detecting the position of a sniper have been developed: *soundometric, thermal imaging and laser ranging method*.

The *sonometric method* is based on the direction finding of the shot sound using several microphones and the calculation of the shooter's position based on the delay of the sound wave (triangulation method). Acoustic sensors can detect pops at significant distances, however, this is difficult to detect if the weapon is equipped with a silencer.

BBN (USA) manufactures the Boomerang system - an acoustic system for detecting a sniper shot that determines the azimuth, range and elevation.

AAI Corporation manufactures PDCue (*Projectile Detection and Cueing*) system. The PDCue system assembly is positioned around a square acoustic array mounted on the vehicle. Microphones listen to the sound (pop) at the barrel bore exit. When such a sound is detected, the system calculates the azimuth direction in relation to the sniper's location and angle of sight. The sonic boom allows calculating the range to the target.

Due to the PDCue system, data is displayed at vehicle speeds up to 100 *km/h* and all shots are recorded in relation to the current position of the vehicle.

Rafael (Israel) produces small arms shot detection system, which is a conventional acoustic shot detection device with microphones mounted on a stand.

The French Pilar complex was developed for the American Special Forces and is also in service with the Australian army. This complex calculates the location of the enemy sniper using the triangulation method, which is based on the processing of the time characteristics of the muzzle and sound waves of the bullets fired by special microphones.

The modern modification of the Pilar Mk-II allows detecting shots of an enemy sniper at a range of up to 1500 *m* with $\pm$ 2º angular error. The complex is available in both portable and mobile versions.

The problem of detecting the location of snipers who are armed with small arms was solved by the specialists of the French company METRAVIB. Special systems make it possible to detect the exact location of the shooting enemy along the trajectory and speed of flying bullets.

The new METRAVIB PEARL systems provide an even more powerful detection tool. They can be installed directly on weapons (up to automatic grenade launchers and large-caliber sniper rifles) and, with their help, specify the location of enemy fighters during a battle.

The system operates on the basis of a simple algorithm that analyzes information from microphones. The complex has special sensors that indicate the arrow in which direction to fire to destroy the enemy. It is easy to conduct not only suppression fire, but also aimed fire by means of such a system. The speed of the METRAVIB PEARL system is faster than the speed of human reaction.

The Russian military is armed with a system for determining the location of snipers called SOVA (acoustic shot detection system). SOVA consists of special sensors for acoustic reception and a powerful computer equipped with specialized software that performs all calculations based on information received from acoustic sensors. The software cuts off any sound interference and processes only information related to the production of a shot and the flight of ammunition. Then the parameters of the acoustic wave are calculated, and these parameters make it possible to calculate the trajectory of the passage of the ammunition and, using these data, determine the coordinates of the place from which the shot was fired.

The advantages of the soundometric method are the following:

— passive detection mode (emits nothing);

— automatic all-weather round-the-clock detection; - circular detection sector;

— simultaneous determination of several firing positions.

The disadvantages of this method include:

— detection only after the shot (and, as a rule, hitting the target);

— low effectiveness against jamming;

— limited possibilities in the conditions of the enemy's use of means of concealing a shot (the use of silencers, the creation of sound interference when a sound wave is reflected);

— relatively short effective detection range.

The *thermal imaging method* is based on the detection of thermal radiation (IR range) of the human body and the thermal "exhaust" of firearms using special devices. The main way to implement this method is to create hardware devices that convert infrared radiation into a visible image.

The advantages of this method include passive detection mode (does not emit anything).

The disadvantages of this method include:

— limited opportunities in conditions of poor visibility (heavy rain, snow);

— limited detection capabilities when the enemy sets false targets or thermal camouflage;

— limited opportunities in the conditions of the enemy's use of fire extinguishing means;

— limited field of vision.

The Radiance Technologies American company has developed the Weapon Watch technology, which allows determining the location of the firing point and the type of weapon in combat conditions a few milliseconds before the fired bullet reaches the target. The computer screen displays a model of the weapon from which the fire was fired (the system verifies the signature of the infrared flash with the existing database), as well as the exact location of the gunman.

The *laser ranging method* consists in emitting laser pulses and receiving a reflected signal from optical systems containing a reflective surface in the focal plane (the effect of retroreflection or «back flare»).

The principle of operation of optoelectronic detection devices is based on the use of the physical effect of retroreflection, which consists in the ability of optical systems to reflect the probe radiation in the opposite direction at an angle close to the angle of incidence. But besides the reflection from the optical target at the input of the laser complex, there is also a large amount of noise - background radiation and various re-reflected beams from surrounding objects.

— active detection mode (emitted signals unmask the system);

— possibility of detection only when it enters the field of view of enemy optical devices;

— limited opportunities in conditions of poor visibility (heavy rain, snow, fog).

One of the important applications of laser technologies from the point of view of safety is the detection and identification of various types of laser sighting systems, night vision devices, laser rangefinders and target designators.

The laser system can not only detect potentially dangerous optical devices, such as sniper sights, but also blind them with the beam of the built-in pulsed laser. Such devices include the Russian portable laser device for optical-electronic countermeasures called PAPV (portable automated sighting device).

The operation essence of the system is relatively simple. An infrared laser beam with (λ = 860 *nm* range and 2 *W* power scans a potentially dangerous sector on the front line of the defense at 6000 *Hz* frequency. The use of two photo detectors in the receiving channel, wide and narrow fields of view, ensures prompt detection of OES with high accuracy, and the use of special algorithms for processing reflected signals excludes the device's response to signals reflected by a glass, eyeglasses and diffusely reflecting objects.

As soon as an optical device enters the range of the device, it is hit with a combat laser, the beam of which not only burns out the optics, but also damages the eyes of the enemy observer.

The energy of the force radiation pulse is 0,2 *J* at λ = 530 *nm* and 1,5 *J* at λ = 1060 *nm*. The pulse repetition rate of force radiation is 0,1 *Hz*.

Range of use is 300—1500 *m*, device weight is 56 *kg*.

The main advantages of the device include:

— high efficiency of suppression of both day and night channels of detected OES ensured by the use of a power laser;

— noise immunity, selectivity and accuracy of the detection system;

— automatic generation of a command to turn on the power laser with precise aiming of the device at the detected OES;

The Israeli company Rafael has developed SpotLite-P — an anti-sniper electronic-optical system for detecting, localizing and neutralizing small arms fire points. The system recognizes fire sources, analyzes them and transmits the coordinates of the target in a short period of time so that the enemy sniper does not have time to change position. The SpotLite-P system consists of an EOU (ElectroOptical Unit) electro-optical tracking system, a FLIR (Forward Looking InfraRed) thermal camera, a Charge-Coupled Device (CCD) camera, a laser a target distance detector, GPS (Global Positioning System) devices and a PTU, as well as a mini-computer for data processing. It can immediately determine the location of several enemy snipers. Fits on a base frame or a jeep and is serviced by one person.

Having considered several methods for detecting a sniper's position, the advantages and disadvantages of each, we can conclude that there is no universal perfect method. The detection efficiency depends on many factors, the main of which are weather conditions, terrain features, the level of training and technical equipment of the sniper. Therefore, further improvement of anti-sniper device systems is required in order to neutralize the threat of a sniper attack at the initial stage of its preparation.

CHAPTER 4. LASER ANTI-BALLISTIC MISSILE (ABM) SYSTEMS AND SPACE DEFENCE (SD) SYSTEMS

Anti-ballistic missile (ABM) — defence is a complex of reconnaissance, radio-technical and fire or any other measures designed to protect guarded objects from missile weapons. Anti-ballistic missile defense is very closely related to air defense and is often carried out by the same systems [20-40, 50-55].

Concerning antiballistic missile defense, one can distinguish *self-defense against missiles, tactical and strategic antiballistic missile defense*.

Self-defense against missiles is the smallest missile defense unit that provides protection against attacking missiles only to the military equipment on which it is installed. All installed ABM systems are auxiliary, and not the main functional purpose for this technology. Self-defense systems against missiles are economically effective for use only on expensive types of military equipment. Currently, two types of self-defense systems against missiles are actively developing: complexes of active protection of armored vehicles and antiballistic missile defense of military ships.

Active protection of armored vehicles is a set of measures to counter attacking projectiles and missiles. The action of the complex can mask the protected object (for example, by releasing an aerosol cloud), or it can physically destroy the threat by a close detonation of a counter-projectile, shrapnel, directed explosion, or in another way.

Active protection systems are characterized by extremely short reaction times (up to fractions of a second), since the flight time of weapons, especially in urban combat conditions, is very short.

An interesting feature is that the developers of anti-tank grenade launchers use the same strategy as the developers of intercontinental ballistic missiles to break through the strategic missile defense - false targets, in order to overcome the systems of active protection of armored vehicles.

Tactical antiballistic missile defense is designed to protect limited areas of the territory and objects located on it (groupings of troops, industry and populated areas) and control bodies and other objects in the operational rear against cruise missiles. Israel left the project, and further development was continued by *Northrop Grumman* resulting in an improved version of the system called *Skyguard*.

The MIRACL CW Chemical Laser (*mid-infrared advanced chemical laser*) is an advanced mid-infrared chemical laser operating on deuterium fluoride DF molecules. The use of DF molecules instead of hydrogen fluoride HF is due to the need to generate at λ = 3,8 μm, that is, in the region of the atmospheric transparency window. Power of 2,2 *MW* was reached in continuous mode.

Northrop Grumman Corporation has been working on the MLD modular combat laser (*Maritime Laser Demonstration*). The initial laser power is 15 *kW*, modular design allows to obtain a total power of up to 105 *kW*. Looking ahead, the output power of the system can be increased to 300—600 *kW*.

Rheinmetall tested a 20 *kW* laser system that destroys an unmanned aerial vehicle (UAV) at a distance of 500 *m* in 3,39*s*, at the Schrobenhausen test site.

In 2014, a presentation of the Israeli Iron Beam laser combat complex was held at the Singapore arms exhibition. It is designed to destroy shells, missiles and mines at short distances (up *to* 2 *km*). The complex includes two solid-state laser systems, a radar system and a control panel.

The Keren Barzel Israeli laser ABM defense system hit 90 % of targets (mines, shells, UAVs) in the course of more than 100 tests in April 2014. The power of the laser used was several tens of kilowatts.

Boeing (American corporation) announced a successful experiment in the use of a combat laser against small-sized unmanned aerial vehicles. The laser was mounted on the Avenger armored vehicle platform (modified HMMWV), which is commonly used by the US Army and Marine Corps for air defense missions. The Laser of the Avenger is capable of using its weapons against such targets, without revealing the position of the troops.

The most famous of the American projects is the laser placed on a Boeing-747-400F aircraft. Boeing was involved in the implementation of this program. The main task of the system is to destroy enemy ballistic missiles in the area of their active trajectory. The laser has been successfully tested, but its practical use remains doubtful. The fact is that the maximum range of destruction is no more than 250 *km*. The Boeing 747 simply cannot reach such a distance if the enemy has at least a minimal air defense system.

Laser weapons are also being developed in Russia, but most of the information about these works is classified. The Russian Peresvet laser complex performs the tasks of anti-aircraft and ABM defense and can be successfully used in the fight against drones. It can be used against any ammunition that uses optoelectronic devices, such as cruise missiles and precision weapons. The principle of operation is based on the illumination of optical reconnaissance systems, including aircraft and satellites, with a laser beam. It can be used to cover (camouflage) the launch positions of ICBMs.

The Peresvet lasers has to complete and insure anti-aircraft missile systems helping them — because of their faster and more efficient controllability — to fight a massive missile strike.

Its effectiveness directly depends on environmental conditions; it works perfectly in fine weather, but fog, rain, snow and other inclement weather can interfere with the laser beam. The complex includes the laser system itself and support vehicles, including those with power sources. Compact nuclear systems are used as pump sources.

Basically, information about the complex is classified, and what type of lasers it is equipped with, is unknown. According to some reports, the complex is also capable of striking orbiting satellites.

The Soviet Union developed hand-held laser weapons for cosmonauts, but in practice these non-lethal weapons were never used.

RFNC-VNIITF (*Russian Federal Nuclear Center — All-Russian Scientific Research Institute of Technical Physics, Snezhinsk, Chelyabinsk Region*) is engaged in the development and testing of nuclear and thermonuclear ammunition. In 2012, a gas laser pumped from a nuclear reactor and operating on an atomic transition of xenon, with 2,03 μm wavelength was created. The output energy of the laser pulse was 500 *J* at 1,3 *MW* peak power. At present, this device is the most compact in terms of the used volume of the active gas medium (the specific energy of laser radiation was 32 J/dm^3).

The US Air Force command ordered the development of new laser modules for combat lasers. According to Aviation Week, the new modules have to be made using nanopowders. It is assumed that the use of mixtures of such powders with different composition in the production of lasers will make it possible to obtain modules with different efficiency and radiation intensity. Other details about this project are still unknown.

Meanwhile, the American company called nGimat has been engaged in similar research commissioned by the US Army since 2015. It has already developed a technology for producing yttrium-aluminum garnet powder suitable for the production of laser amplifiers. The company also announced that it could make lasers from the powder.

As the newspaper notes, nGimat has already held negotiations with the US Air Force to finance the development of a new technology for the production of highly purified yttrium-aluminum garnet nanopowders. According to the company, such powders will make it possible to manufacture high-power laser modules. Preliminary studies for the project are already underway.

Yttrium-aluminum garnet is used today in the production of solid-state lasers. For example, yttrium-aluminum garnet doped with neodymium ions makes it possible to obtain a laser with radiation at 1,064 *μm* wavelength. There are lasers based on garnet doped with erbium or ytterbium ions. Various doping allows obtaining emitters of different wavelengths and powers.

In mid-March of this year, the American company called Lockheed Martin announced that laser weapon technology has already been sufficiently developed and reliable, which means that the military can adopt combat lasers at any time. The company's combat lasers can be installed on almost any platform, including a vehicle, ship or aircraft.

We are talking about lasers with 15—30 *kW* power. More powerful systems are still being developed, and their development is constrained not so much by the technical side as by parallel research in various fields, including atmospheric influence. In addition to Lockheed Martin, the American aircraft manufacturer Boeing also has a ready-made combat laser and has developed a weapon with 30 *kW* capacity.

5.2. Naval Forces

In addition to lasers for the ground forces of the US armed forces, the Americans are persistently developing similar weapons for the naval forces and in the future intend to equip destroyers, cruisers and, possibly, aircraft carriers or LCS-class ships with combat lasers (*Littoral Combat Ship*) [50-60].

The US Navy funded several laser weapons systems under one large SNLWS (*Surface Navy Laser Weapon System*) program.

The first such system is HELIOS (*High Energy Laser with Integrated Optical-dazzler and Surveillance*) laser complex designed to protect both from drones and missiles, and from small sea vessels.

The complex is equipped with a 60-kilowatt laser, which can reach a power of 150 *kW,* and is directly connected to the ship's power source, as well as to the Aegis automated combat system (*protection*), which uses onboard radar for targeting.

The HELIOS program includes a 60 *kW* fiber optic laser to combat UAVs and small boats, a long-range reconnaissance and surveillance sensor system integrated with the ship's Aegis combat control system, and a low-power blinding laser to disrupt the operation of drone surveillance systems.

The second system is a low-power laser installation ODIN (*Optical Dazzling Interdictor, Navy*) designed to blind and disable UAV sensors. The ODIN system includes a telescopic subsystem, mirrors and two laser emitters, a set of sensors for coarse and precise targeting.

A prototype 14 *kW* FEL laser was demonstrated in 2011. At the moment, the state of work on this laser is unknown; it was planned to gradually increase the radiation power up to 1 *MW*. The main difficulty is the creation of an electron injector of the required power. The appearance of FEL lasers of sufficient power is difficult to expect in the near future, rather it will happen after 2030.

Free electron lasers are large in size, which complicates their placement on small-sized carriers. In this sense, large surface ships are the optimal carriers of this type of laser.

Small UAVs are a definite threat to ships. They can be used both for reconnaissance and for hitting the most vulnerable points of the ship, for example, radar. The use of missile and cannon weapons to destroy such UAVs often turns out to be ineffective, and the problem is solved with the help of a powerful laser.

Anti-ship missiles (ASM), against which laser weapons are used, can be divided into two groups:

— low-flying subsonic and supersonic ABM defense systems;

— supersonic and hypersonic ABM defense systems attacking from above.

In relation to low-flying ABM defense systems, an obstacle for laser weapons of systems can be the curvature of the earth's surface, which limits the range of a direct shot, and the saturation of the air with water vapor. The laser power must be over 300 *kW*.

For high-altitude ABM defense systems, the affected area is limited by the capabilities of the guidance systems and the laser power. For hypersonic ABM defense systems, the power of laser systems must be greater than 1 *MW*.

Placing laser weapons on submarines with a power greater than 300 *kW* with output through the periscope will allow the submarine to hit enemy anti-submarine weapons from periscope depth.

In the United States, acoustic laser guns are being developed, which create intense sound vibrations at a great distance from the source. This will allow them to be used to create acoustic interference or decoys for enemy torpedoes and sonars.

Placing laser weapons on warships has both pros and cons.

On modern ships, the power of laser weapons is limited by the capabilities of electric generators, but modern ships can remove this limitation. There is much more space on ships than on ground and air carriers, so there are no problems with the placement of large-sized equipment. Finally, there are unlimited possibilities for cooling laser systems.

In the 1990s, the US Department of Defense conducted tests to intercept unmanned aerial vehicles and supersonic anti-ship missiles. But the use of a chemical laser as a ship weapon was abandoned due to the need to store and use toxic components, as well as because of the complexity of operation and maintenance.

Currently, American companies, including Northrop Grumman, Boeing and Locheed Martin, are developing laser self-defense systems for ships based on solid-state and fiber lasers.

The military of other countries are also aiming at creating fiber lasers with a power level of 100 *kW*, necessary for the reliable destruction of targets at a distance of several kilometers.

The Chinese company Pole Technologies, the Israeli Rafael and the German company Rheinmetall have already developed lasers that are as powerful as the American prototype.

In addition to the United States, Great Britain is showing the greatest interest in sea-based lasers. The lack of a laser industry does not allow the project to be implemented on its own, in connection with which, in 2016, the UK Ministry of Defense announced a tender for the development of an LDEW (*Laser Directed Energy Weapon*) technology demonstrator, in which MBDA Deutschland won. In 2017, the consortium unveiled a full-size prototype of the LDEW laser.

Earlier in 2016, MBDA Deutschland presented the Laser effector, which is installed on land and sea carriers and is designed to destroy UAVs, missiles and mortar shells. The complex provides defense in the 360-degree sector, has a minimum reaction time and is capable of repelling strikes coming from different directions. The company reports that its laser has huge development potential.

5.3. Air Forces

In 2006—2011, the YAL-1A laser placed on a Boeing-747-400F aircraft was created and tested in the USA. A powerful on-board laser could destroy various enemy objects, primarily intercept ballistic and cruise missiles with a nuclear warhead. The planned advantage over other means is the ability to destroy missiles in the initial phase of the flight path. The system included the following laser units [50-65]:

— TILL (*Track Illuminator Laser*) laser for target detection and tracking, as well as adjusting the parameters of the laser optical system, with which the target will be hit;

— BILL (*Beacon Illuminator*) laser to analyze the effect of the atmosphere on the distortion of the beam path and compensate for atmospheric distortion;

— HEL (*High-Energy Laser*) - the main combat chemical laser, but the SHEL (*Surrogate High Energy Laser*) simulator was used for testing.

The HEL laser consists of six energy modules-chemical lasers with an active medium based on oxygen and metal iodine (*Chemical oxygen iodine laser - COIL*), which generate with λ = 1,315 *μm* wavelength.

The complex has been successfully tested to destroy liquid and solid propellant ballistic missiles. The target was defeated in several stages. The TILL laser was used to detect and track the target at the first stage. The BILL laser was then used to eliminate atmospheric effects on targeting accuracy. After that, a fire was made by a megawatt-power combat laser, which caused the destruction of the missile structure heating it to critical temperatures. The target hitting range was about 100 *km*, and the time spent on the whole process was of the order of hundreds of seconds.

But due to a cut in the military budget in 2011, the program was closed, although the main reason is the futility of a chemical laser. HEL laser ammunition is limited by chemical fuel supplies on board and does not exceed 40 rounds. When the laser operates, a large amount of heat is generated, which is removed by a stream of superheated gas at 1800 *m/s* speed, that is, approximately five times the speed of sound. The combination of high temperatures and explosive laser components can lead to dire consequences.

In the Soviet Union in the mid-1970s, an A-60 experimental laboratory was created on the basis of the Il-76 aircraft with laser weapons to suppress enemy reconnaissance. The aircraft received a powerful power supply system and protection against radio-electronic effects of the enemy, as well as ultra-precise navigation. In 2010, work on the military aviation laser system was continued, but in 2011 it was suspended, and the equipment from the A-60 was partially dismantled.

According to information from 2018, work continues in Russia on a military aviation laser system to combat enemy satellites. But there is no open information about the types of lasers used and the wavelength ranges.

What are the consequences of equipping combat aircraft with laser systems? With modern radar and optical guidance systems, this will ensure self-defense of the fighter from enemy missiles. When the laser power exceeds 100 *kW*, 2—4 incoming air-to-air or ground-to-air missiles can be destroyed. Combined with missile weapons such as CUDA (*Compute Unified Device Architecture*), the chances of an aircraft equipped with laser weapons to survive on the battlefield will increase over many times.

The maximum damage can be caused to missiles with optical and thermal guidance, since their performance depends on the functioning of the sensitive matrix. The use of filters for a specific wavelength will not help, since the enemy can use lasers with different wavelengths, and the absorption of the laser energy by the filter with a power of more than 100 *kW* will cause its destruction.

The defeat of missiles with a radar homing head is also possible, since the fairing on the multiple reentry vehicle can be damaged. Man-portable air defense systems (MANPADS) with thermal guidance of the Igla or Stinger type, as well as surface-to-air missiles, long-range air defense systems, can also be hit with a laser.

5.4. Space-basing

The US has been developing *Space Based Laser* (SBL) for many years in order to intercept space targets. The projects are being carried out by the BMDO (*The Ballistic Missile Defense Organization*) agency with the participation of Boeing, Lockheed Martin and TRW Inc [50-65].

A series of space studies was carried out to determine the architecture of orbital platforms for high power lasers, taking into account the requirements of the optics and the number of platforms. As a result, the optimal number of space platforms in the amount of 20 in an orbit with 1300 *km* altitude was determined, which was supposed to provide complete protection against intercontinental ballistic missiles (ICBMs). The SBL group can destroy ICBMs depending on the flight altitude in 2—5s within a radius of 4000 *km* from the platform.

Each platform includes four main components: an SBL laser device, optics and beam control system, an acquisition, tracking, targeting and fire control (ATF/FC) system, and a nuclear laser pumping system. The SBL is 8 *MW* Hydrogen Fluoride Laser with a parabolic mirror, the calculated mass is 35 *tonnes*. The cost of the *Space Based Laser* program is over $ 80 billion.

The only thing that so far restricts the United States from launching combat lasers into space is the lack of technological and technical solutions for space nuclear systems.

In conclusion, let us ask the question, what types of lasers are the most promising for military applications?

With all the advantages of gas-dynamic and chemical lasers, they have significant disadvantages: the need for consumable components, launch inertia (according to some sources, up to one minute), significant heat release, large dimensions, and the yield of spent components of the active environment. Such lasers can only be deployed on large carriers.

At present, taking into account the above-mentioned negative factors, the most promising are solid-state and fiber lasers, which require only sufficient electric power to operate.

An important advantage of fiber lasers is the ability to combine several modules into one complex to obtain higher power.

The world's largest company for the development and production of fiber lasers IPG Photonics headquartered in Oxford, Massachusetts USA, develops and manufactures continuous-wave fiber lasers in Russia (Fryazino, Moscow region). These are ytterbium low-mode laser systems (YLS) with power from 1 *kW* to 500 *kW* in a wide spectral range with efficiency up to 50 %. The divergence characteristics of IPG fiber lasers are far superior to other high power lasers. Fiber lasers have a monolithic, all-solid-state fiber-to-fiber design that does not require mirrors or optics for alignment or adjustment. The lasers are water-to-air or water-to-water cooled. Fiber lasers are generally smaller and lighter than traditional lasers and save valuable space. This circumstance is especially important for their placement on aircraft.

Despite active development and many advantages of laser weapons, it has significant disadvantages.

First, there is a lot of electricity consumption. Consequently, powerful laser systems require bulky generators, which considerably decrease the maneuverability of complexes with such systems.

Second, laser weapon strikes target only with direct laying, and this limits its applications on dry land.

Third, laser beam can be reflected, using special protective layers from relatively inexpensive materials.

Nevertheless, at present in many technologically effective countries of peace continue the developments of laser systems for the combat employment. Experts consider that the lasers will start to mass enter the troops already at the beginning of the following decade.

CHAPTER 6. QUANTUM DATA SECURITY

The idea of using quantum objects to protect information from forgery and unauthorized access was first expressed by Stefan Weisner in 1970. Ten years later, scientists Bennett and Brassard, who were familiar with Weissner's work, proposed using quantum objects to transmit the secret key. In 1984 they published a paper describing the BB84 quantum key distribution protocol [71-83].

The data carriers in the BB84 protocol are photons polarized at angles of 0, 45, 90, 135 degrees.

The idea was later developed by Eckert in 1991. The method of quantum theory-based cryptography is the observation of quantum states of photons. The sender sets these states, and the receiver registers them. It uses the Heisenberg indeterminacy principle, when two quantum quantities cannot be measured simultaneously with the required accuracy. Thus, in case the sender and the receiver have not agreed between themselves which type of polarization of quanta to take as a basis, the receiver can destroy the signal sent by the sender without receiving any useful data. These features of the behavior of quantum objects formed the basis of the quantum key distribution protocol.

In 1991, Bennett used the following algorithm to register changes in data transmitted using quantum transformations:

— the sender and receiver agree on an arbitrary permutation of bits in the strings to make the error positions random;

— the strings are divided into blocks of k size (k is chosen so that the probability of an error in a block is minor);

— for each block, the sender and the receiver calculate and openly notify each other about the results obtained. The last bit of each block is removed;

— for each block, where the parity turned out to be different, the receiver and the sender perform an iterative search and correction of incorrect bit;

— in order to exclude multiple errors that may not be noticed, the operations of the previous paragraphs are repeated for a larger k value’ using femtosecond lasers it is possible to get supercontinuum, which implies a set of discrete closely spaced spikes of radiation decomposed in the frequency domain. The encryption method consists of cutting out one or several discrete frequencies from the spectrum of the supercontinuum. This makes it possible to form the code first in binary (fig. 6.6).

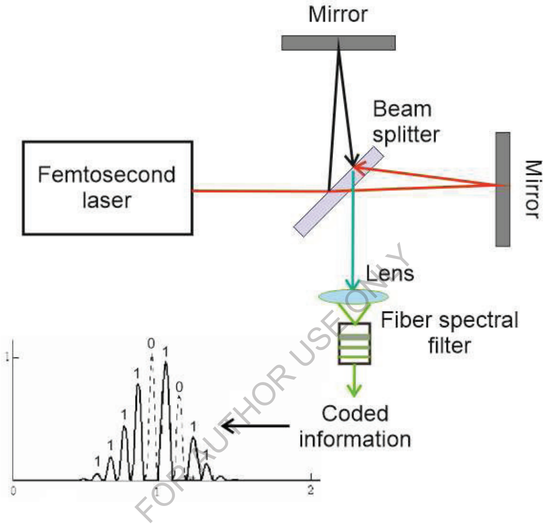


Fig. 6.6. Quantum information encoding device

For this, a Michelson interferometer is used. By changing the length of one of its shoulders, it changes the interference pattern, which makes it possible to control the spectral characteristic of the laser within small limits. After that, a set of narrow-band frequency filters «Bragg gratings» are used, which are applied directly in the core of the optical fiber. The creation of such a device will open up new opportunities for high-speed transmission of classified information over fiber-optic communication lines, as well as the development of THz laser technology.

6.3. Vulnerabilities in Quantum theory-based cryptography

Although quantum key distribution is positioned as invulnerable to hacking, specific implementations of such systems allow a successful attack and steal the generated key. Here are some types of attacks on cryptosystems with quantum key distribution protocols. Some attacks are theoretical, others are quite successfully applied in real life [71-83].

1. Attack with a beam splitter - consists in scanning and splitting pulses into two parts and analyzing each of the parts in one of two bases.

2. Trojan horse attack consists of scanning a pulse through an optical multiplexer towards the sending or receiving side. The pulse is divided into two parts for synchronous detection and goes to the decoding circuit, while the distortion of the transmitted photons does not occur.

3. Coherent attacks based on relay tactics. The attacker intercepts the transmitter's photons, measures their state, and then sends pseudophotons in the measured states to the recipient.

4. Incoherent attacks, in which photons from the transmitter are intercepted and entangled with a group of transmitted single photons. The group status is then measured and the changed data is sent to the recipient.

5. The blinding attack of avalanche photodetectors, which was developed by Vadim Makarov's research team, allows an attacker to obtain a secret key so that the recipient does not notice the interception.

6. Photon splitting attack. It consists in the detection of more than one photon in a pulse, its removal and entanglement with the sample. The remaining unchanged piece of information is sent to the receiver, and the interceptor receives the exact value of the transmitted bit without introducing errors into the sifted key.

7. Spectral attack. In case photons are created by four different photodiodes, they have different spectral characteristics. The attacker can measure the color of the photon, not its polarization.

Quantum cryptography research is developing at a rapid pace. In the near future, data security methods based on quantum data will be used primarily in top-secret military and commercial applications.

On June 23, 2015, Toshiba announced the beginning of preparations for the market launch of an uncrackable encryption system. According to the developers of the new technology, the best way to protect information on the network is to use one-time decryption keys. The problem is in the secure transfer of the key itself. Quantum cryptography uses the laws of physics for this, in contrast to the usual methods based on mathematical algorithms. The key in the system created by Toshiba is transmitted in the form of photons generated by a laser - the light particles are delivered via a special fiber optic cable that is not connected to the Internet. The nature of photons is such that any attempts to intercept data alter this data and this is immediately detected, and since the one-time key must have the same size as the encrypted data, the repeated use of the same template is excluded, which makes decoding impossible without the correct key. Toshiba started researching quantum cryptography technologies in 2003. The company presented its first system in October 2013, and in 2014 the company achieved stable transmission of quantum keys over standard fiber for 34 days.

For all its fundamental advantages, this method has significant basic limitations: due to the attenuation of the light signal, the transmission of photons (without a repeater) is possible at a distance of no more than 100 *km*. Photons are sensitive to vibration and high temperatures, which also complicates their transmission over long distances. And for the implementation of the technology, equipment is required, where one server costs about $ 81 thousand. As of June 24, 2015, Toshiba did not abandon plans to launch long-term system testing for method verification. During testing, which began on August 31, 2015, encrypted genome analysis results obtained at the Toshiba Life Science Analysis Center were transmitted to the Tohoku Medical Megabank (at Tohoku University), at a distance of approximately 7 *km*. The program was designed for two years, until August 2017. The study monitored the stability of the transmission rate during long-term operation of the system, the influence of environmental conditions, including weather, temperature and the state of the optical connection.

The experiment was successful, and commercial use of the technology will become possible in a few years. In 2020, the company expects to begin providing services to government organizations and large enterprises. With the technology becoming cheaper, the service will also come to private users.

On September 30, 2015, Acronis announced plans to implement quantum encryption technologies into its data protection products. Swiss ID Quantique will assist it in this matter, the investor of which is the fund QWave Capital created by Sergey Belousov.

Acronis will develop quantum cryptography technologies.

The vendor plans to equip their products with them and believes that this will provide a higher level of security and privacy.

Acronis expects to be the first company on the market to implement such protection methods.

The Swiss company ID Quantique, with which the vendor entered into an agreement, will become Acronis' partner in the development of quantum cryptography.

ID Quantique is a company associated with Acronis CEO, Sergey Belousov, - he is the founder of QWave Capital, which is one of the investors in ID Quantique.

One of the technologies that Acronis plans to implement in its solutions is quantum key distribution.

The encryption key is transmitted over the fiber optic channel using single photons.

An attempt to intercept or measure certain parameters of physical objects, which in this case are carriers of information, inevitably distorts other parameters.

As a result, the transmitter and receiver detect an attempt to gain unauthorized access to information.

It is also planned to use quantum random number generators and encryption resistant to quantum algorithms.

Toshiba announced the invention of a new quantum key distribution protocol called Twin-Field QKD (Quantum Key Distribution) in May 2018. The protocol allows transferring keys over distances of more than 1000 km without trusted repeaters or quantum repeaters. It was promised to be tested on a pilot plant in 2019. Toshiba demonstrated an operating quantum cryptography system that provided an average monthly transfer rate of quantum keys over conventional fiber at 10.2 Mbps in September 2018. These facts indicate the indisputable relevance of the development of quantum cryptography, which is based on laser light sources.

CONCLUSIONS

The monograph discusses the types of lasers and their main parameters for use in military optoelectronic equipment.

The first chapter discusses the basic physical principles of laser operation.

Principles and types of pumping of lasers, from lamp pumping to chemical, gas-dimamic and atomic pumping.

Also in the first chapter, the principles of operation of gas, gas-dynamic, solid-state, semiconductor, fiber, free electron and atomic lasers are analyzed.

The principles of the effect of laser radiation on the elements of rocket and space systems, the hardware of unmanned aerial vehicles and human vision organs are considered.

Special attention is paid to the influence of the atmosphere on the parameters of laser radiation.

The second chapter is devoted to laser search and navigation systems, namely laser range finders, navigation systems such as Glonass, GPS, as well as their development with the use of optoelectronic devices.

The third chapter describes laser guidance and suppression systems.

Their basic principles of operation and existing devices in this direction are described.

The fourth chapter describes the development of laser anti-ballistic systems and space protection systems.

The fifth chapter is devoted to the development of directed energy weapons and their application in various basing methods.

The sixth chapter describes the development of quantum theory-based cryptography (optical data security).

The history of creation and implementation of the first devices of quantum theory-based cryptography is considered.

The principles of data transmission using quantum channels are considered.

The following quantum data transfer protocols are described: BB84, DPS, COW, E91.

Special attention is paid to the optical circuits of information encoding devices by phase, polarization and "entangled states" methods.

A new data coding scheme using fiber femtosecond lasers and photonic crystals is considered and described.

The points of vulnerability of quantum information security systems, as well as the modern development of such systems are explained.

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The usage of lasers in military equipment

Part 1

Monograph

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